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Fracture mechanics solution of confined water progressive intrusion height of mining fracture floor

Lu Haifeng [a,b,*], Yao Duoxi [a], Shen Dan [a], Cao Jiyang [a]

[a] School of Earth and Environment, Anhui University of Science and Technology, Huainan 232001, China
[b] State Key Laboratory of Coal Resources and Safe Mining, China University of Mining & Technology, Beijing 100083, China

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ABSTRACT

In order to obtain the value of confined water progressive intrusion height of mining fracture floor, the analysis equation was deduced based on the fracture extension theory of the fracture mechanics. Furthermore, the influence of some parameters (e.g., advancing distance of working face, water pressure, initial fracture length and its angle) on confined water progressive intrusion height were analyzed. The results indicate that tension-shearing fracture of floor is extended more easily than compression-shearing fracture under the same conditions. When floor fracture dip angle is less than 90°, tension-shearing extension occurs more easily on the left edge of the goaf. If fracture dip angle is larger than 90°, it occurs more easily on the right edge of the goaf. The longer the advancing distance of working face is, the greater initial fracture length goes; or the larger water pressure is, the greater possibility of tension-shearing extension occurs. The confined water progressive intrusion height reaches the maximum on the edge of the goaf. Field in situ test is consistent with the theoretical analysis result.

1. Introduction

Floor water invasion is the main problem of hydrogeology geology and engineering geology in the coal seams above confided aquifer in China, which seriously affects the safety of mining production. Therefore, the study on the mechanism of water invasion and the effective reducing water invasion accidents are the urgent need for coal industry [1–3]. Domestic and foreign scholars have carried out a lot of research on floor water invasion problem. Several water invasion criteria and theories had been proposed, i.e., the water invasion coefficient method [4], the theory of tension fissure and failure at zero position [5], the progressive intrusion theory [6], the plate model theory [7–8], the "Down Three Zone" theory [9–10], and the key strata theory [11–14]. They revealed the existed mechanism of water invasion in all aspects. It had played a positive guiding roles in mining security production. Both "the progressive intrusion" theory and "Down Three Zone" theory involve the parameters of confined water progressive intrusion height in the practical application.

By using the theory of elastic–plastic, Zhang considered the water-resisting floor as a full thin plate, and deduced the expression formula of confined water progressive intrusion height caused by mining [5]. According to the hydraulic fracturing test, it could be concluded that swelling soft rock due to the influence of water was conducive to prevent the confined water intrusion by Zhang et al. [15]. By using the methods of similar material simulation in laboratory and field in situ tests, the natural intrusion height of floor and the mining progressive intrusion height were determined by Wang et al. [6]. On the basis of laboratory simulations and in situ tests, the influent factors of rock water-resisting performance and intrusion height were discussed to explain the confined water natural progressive intrusion mechanism by Yin et al. [16]. Under the mining condition, the mechanism of floor confined water progressive intrusion was analyzed by physical simulation in laboratory by Gu et al. [17]. The value of progressive intrusion height was calculated through similar simulation in laboratory by Jiang et al. [18]. The floor water-resisting and aquifer were divided into four zones by Wang et al. [19]. And the value of confined water progressive intrusion height was calculated.

At present, under the condition of mining, the determination of floor confined water progressive intrusion height is mainly based on the laboratory tests, field in situ tests and numerical simulation methods. However, only little theoretical analysis is applied. In addition, the existing theoretical analysis is derived from the elastic–plastic theory which assumes the floor to be an intact rock mass. But the natural rock mass contains such a variety of fractures and other discontinuities that confined water will make the

* Corresponding author. Tel.: +86 13625547128.
E-mail address: luhaifeng7571@126.com (H. Lu).

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fracture extended and coalesced under the condition of high water pressure and mining. Therefore, fracture extension criterion of fracture mechanics was introduced into the calculation of confined water progressive intrusion height in this paper. Considering the impact of mining and water pressure, fracture mechanics model of confined water progressive intrusion were built by different types of compression-shearing and tension-shearing fracture. And the influence of some parameters (advancing distance, water pressure, fracture length and its dip angle, etc.) on confined water progressive intrusion height were analyzed. Finally, research results were applied in practice, and the calculated results were compared with the filed in situ tests.

2. Fracture mechanics model of confined water progressive intrusion height

In pre-mining, due to the presence of natural fractures in the floor, water rise to a certain height along the natural fractures, which is called natural progressive intrusion height of confined water. The height is generally small, as shown in Fig. 1a. After mining, the maximum depth of coal seam floor destruction is h_a, as shown in Fig. 1b. Meanwhile, under the coupling influence of mining and water pressure, the fractures of natural progressive intrusion zone further extend upward, forming confined water progressive intrusion zone. Both the natural progressive intrusion zone and progressive intrusion zone are called confined water intrusion zone. The maximum height is h_c, as shown in Fig. 1b. If mining failure zone of coal seam floor and confined water intrusion zone connect with each other, the floor water invasion will occur. If not, complete water-resisting zone h_b will exist between mining failure zone of floor and confined water progressive intrusion zone, as shown in Fig. 1b. Therefore, correct calculation of the value of confined water progressive intrusion height is of great significance to reasonable evaluation of floor water invasion.

Because natural progressive intrusion height is generally small, its value is often ignored. Floor water invasion is mainly caused by confined water progressive intrusion, thus this paper aims to analyze the progressive intrusion height. Firstly, stress solutions of fracture face were given out using the theory of elastic mechanics. Secondly, based on stress solutions, the fracture extension criterion of fracture mechanics was applied to judge the extension and the branch fracture length was obtained. Lastly, the value of confined water progressive intrusion height was calculated by space geometric relationships of the branch fractures.

2.1. Model construction

For longwall mining face, surrounding rock mass in the middle of the stope is selected as research object along the advancing direction of working face, which could be regarded as a plane strain problem. Referring to the existing research [7], the stress distribution of stope section could be substituted for the equivalent mechanical model, as shown in Fig. 2 (without considering the weight of the fallen breaking rock in the goaf). As shown in Fig. 2, the equation of equivalent stress is $q = (n+1)\gamma H/2$, where H is the seam depth and γ is the average density of the overlying rock and soil. In Fig. 2, l_1 is the length of goaf. And l_2 is the range of supporting pressure, and its length is generally two times of the distance from working face ends to the peak stress zone [7].

According to the existing research [20], when the fracture spacing is greater than the fracture length, the impact of the interaction between adjacent fractures and the fracture on its tip stress field can be ignored. For the convenience of calculation, the single fracture was selected as the research object in this study. As shown in Fig. 2, the length of fracture is $2a$ and the dip angle is α. The fracture is located in the bottom of water-resisting floor. The scale of micro-fracture is relatively small in terms of the entire water-resisting floor, and its impact on the stress distribution could be neglect. Hence, the stress of any point in the floor could be approximately calculated as homogeneous elastic material. In view of the complexity of three-dimensional fracture problems, the fracture is considered as two-dimensional fracture and expends within the plane of the selected section.

2.2. Elastic mechanics solution of stress on fracture surface

Subtracting the original rock stress from the overlying coal load, it could be concluded that the equivalent additional stress of the side coal is $(n-1)\gamma H/2$ and the additional stress in goaf is $-\gamma H$, as shown in Fig. 3. The additional stress caused by the whole load at any point of floor could be obtained from the theory of elasticity. The results are showed in Eqs. (1)–(3) (normal stress is positive to

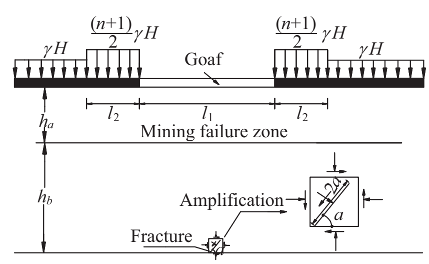


Fig. 2. Sketch of micro-fracture in mining seam floor.

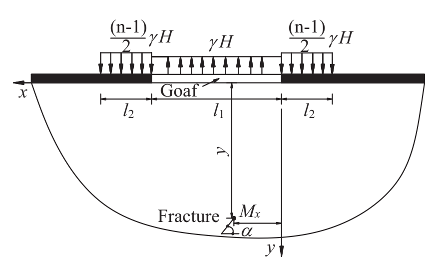
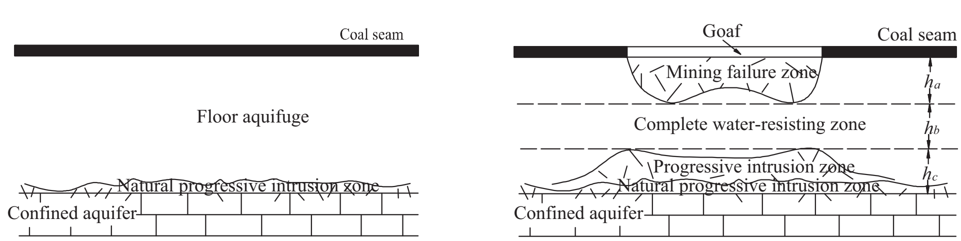


Fig. 3. Sketch of calculating additional stress of fracture's upper endpoint M.



(a) Natural progressive intrusion zone before mining (b) Progressive intrusion zone by mining

Fig. 1. Sketch of floor failure during mining above a confided aquifer.